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RESEARCH PAPER

Habitat suitability change of red-crowned crane in Yellow River Delta Nature Reserve

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Abstract: Habitat loss and fragmentation are mainly associated with population decrease of endangered species and biodiversity loss. The habitat suitability maps of red-crowned crane *(Grus japonensis)* in 1992, 1999 and 2006 were produced by using Ecological Niche Suitability Model (ENSM) in Yellow River Delta Nature Reserve (118°33′–119°20′E longitude, 37°35′–38°12′N latitude), Shandong Province, China. Based on the habitat suitability maps, the causation and change law of habitat loss and fragmentation of red-crowned crane were analyzed by selecting a series of landscape pattern indices. Results showed that due to scarcities of fresh water sources, habitat suitability of red-crowned crane in 1999 was inferior to that in 1992 and 2006 no matter whether human disturbances existed or not. Besides, human disturbance activities, especially road disturbances, increased rapidly during the period of 1992–2006. This worsened the habitat loss and fragmentation of red-crowned crane, and led to degrading habitat suitability of red-crowned crane in 2006, compared with that in 1992. In conclusion, fresh water sources and human disturbance activities are the two main factors that drive the habitat suitability change of red-crowned crane.

Keywords: red-crowned crane; Yellow River Delta Nature Reserve; habitat suitability; habitat loss; habitat fragmentation

Introduction

Habitat loss and fragmentation caused by the increase of human populations and concomitant land-use intensification (e.g. cultivation, grazing, urban development) are the main causation of elevating species extinction risk (Andren 1994; Fahrig 1997; Cushman 2006) and accelerating global biodiversity loss (Burkey 1995; Wilcove et al. 1998; Gibbs 1999; Laurance et al. 2002; Fahrig 2003). For protecting the organisms and their habitats, an expansion of research has been motivated to focus on how habitat fragmentation affects the distribution, abundance, and persistence of population inhabiting patchy landscapes (Dooley et al. 1998; Schmiegelow et al. 2002; Flather et al. 2002; Stephens et al. 2003).

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Red-crowned crane *(Grus japonensis)* is a rare species that is classified as endangered species (IUCN 2007). Due to its sensitivity to human disturbance activities, it is a specialist that only lives in the native wetlands without human disturbance activities. Furthermore, Red-crowned crane is a long-distance migrant that breeds in northeast Asia and winters in southern China. Within recent two decades, most studies were mainly concentrated on red-crowned crane's habitat selection (Li et al. 1997; Li et al. 1999; Ma et al. 1998; Su et al. 2006), breeding, wintering and territory behaviors (Liu 1990; Li et al. 1998; Li et al. 1999; Li et al. 2000; Liu et al. 2001, Wu et al. 2002; Zhang et al. 2001) at its vital breeding and wintering sites. Moreover, because of its large body in size, low reproduction rate, and rigorous habitat preference, red-crowned crane is more prone to be threatened by the environmental changes of wetlands. Wetland loss and fragmentation are the main reasons contributing to the decline of red-crowned crane population (Wan et al. 2002; Hu et al. 2004; Zhang et al. 2006)

Yellow River Delta Nature Reserve (YRDNR) is a key site for red-crowned crane in migration and wintering. Since 1992, the habitat of red-crowned crane in YRDNR has been changed greatly due to natural succession and human or natural disturbances, which led to the fluctuation of red-crowned crane in population size. Therefore, how to protect the habitat of red-crowned crane has become the most urgent issue for local managers. Su et al. (2004) conducted the habitat analysis of red-crowned crane at the scale of Yellow River Delta, but we think the scale studied was too large to reflect the real habitat dynamics of red crowned crane. In fact, the habitat of

red-crowned crane is mainly marsh and wetland near the coast, which is almost located at YRDNR. Thus, the more reasonable and appropriate habitat scale of red-crowned crane should be in YRDNR.

In the present study, based on the landscape ecology theory and the habitat suitability maps of red-crowned crane, the habitat loss and fragmentation of red-crowned crane in YRDNR since 1992 were analyzed and quantified. Moreover, the factors that drive its habitat suitability change were also discussed.

Study site

YRDNR, which was built up in 1992, covering an area of 153 000 ha, is located at the mouth of the Yellow River in the northeast of Shandong Province, China (118°33′–119°20′E longitude, 37°35′–38°12′N latitude). It is a national nature reserve for protection of newborn wetland ecosystem, and rare and endangered birds. As a whole, YRDNR consists of two parts, including current and old (before 1976) courses of Yellow River, and three management stations that contain Yellow River Estuary, DaWenLiu and YiGianEr. YRDNR provides the most suitable habitat environment for waterfowls, with plenty of tidal flats and marshes, and abundant wetland vegetation and fresh water organisms. Moreover, YRDNR is one site of the East Asia birds' migration network, a membership of East Asia-Australia wading birds network, and also a biosphere reserve of China MAB (Zhao et al. 1995). However, the second largest oil field of China-Shengli oil field is located here, which threats to the waterfowl's habitat.

Materials and methods

Data sources and processing

The data in this study are extracted from Landsat Thematic Mapper (TM) image data of 1992, 1999, and 2006, respectively. Firstly, we performed the geometric rectification to the three images by using ground control points (GCP) identified and selected from a topographic map at a scale of 1:50000. Secondly, we applied unsupervised classification to rectify images and generate clusters using ISODATA cluster analysis. Thirdly, field data collected in 1999 and 2006 were used to identify training classes and to label and merge clusters for identification. Finally, the identified clusters were subsequently used in a maximum likelihood classification to generate a vegetation map. The vegetation types consist of forest, Chinese tamarisk shrub, reed meadow, reed marsh, seablite tidal flat, bare tidal flat, salt pan, fishpond, deep water area, and farmland. The SPOT-5 image and topographic maps (1:50000) of 1986 and 1998 were used as the supplements to extract the roads, oil wells, residential area, water source area, and tide ditches from the TM images. All the data was stored as raster data after data processed.

Habitat suitability map of red-crowned crane

Red-crowned crane is a wetland species being accustomed to the habitat of marsh, tidal flat with sparse vegetation and little disturbances (Wan et al. 2002; Liu et al. 2001; Li et al. 1999; Li 2002; Wu et al. 2002; Su et al. 2006). Furthermore, previous studies showed that red-crowned crane was apart from roads, with the nearest distance of 200 m or 300 m, due to being susceptive to human disturbance activities (Xiao et al. 2001). Therefore, according to its habitat requirements, we selected vegetation types, water sources and human disturbances as habitat factors that constrained the distribution of red-crowned crane. The vegetation factor includes ten vegetation types extracted from the TM images, water source factor includes the distance to shallow water area and tide ditch, and human disturbance factor includes the distance to road, oil well and residential area. All affected factors were transformed into three grades by using fuzzy evaluation method: suitable (1), moderately suitable (0.667), and unsuitable (0) (Table 1).

Table 1. Value of suitable habitat factors

Habitat factors		Suitable habitat	Moderately suitable habitat	Unsuitable habitat
Vegetation type		Reed marsh, Seablite tide flat	Salt pan, fishponds, reed meadow, bare tide flat	Forest. Chinese tamarisk shrub, farmland, large deep water area (e.g.: reservoir, Yellow River)
Water resource	Distance to shallow water area	0–500 m	500–1000 m	>1000 m
	Distance to tide ditch	0–500 m	500–1000 m	>1000 m
Human disturbances	Distance to road	>500 m	200–500 m	<200 m
	The distance to oil well	>500 m	300–500 m	<300 m
	Distance to residential area	>500 m	300–500 m	<300 m
Value		1	0.67	0

The Ecological Niche Suitability Model (ENSM), which is based on Shelford's Low of Tolerance (Odum 1971; Ou Yang et al. 1996), was introduced to calculate the habitat suitability. Sheloford's Law states that an organism grows and reproduces under a given environment space, and its growth and reproduction should remain within its tolerance range governed by the limiting environment factors; otherwise, it cannot survive at all. According to this concept, the ENSM can be expressed as follows (Chen et al. 1999):

$$S_j = \prod_{i=1}^{n} S_i \tag{1}$$

where S_j is the suitability value of one raster cell, S_i is the value of various habitat factors, and n is the number of habitat factors. If any value of the factors is equal to 0, S_j is equal to 0. When all the factors are equal to 1, S_j is equal to 1. Based on S_j value, the

habitat suitability of red-crowned crane can also be classified as three grades: suitable (1), moderately suitable ($0<S_j\leq0.667$), and unsuitable (0).

The ENSM was performed on the ArcGIS platform. Firstly, the natural factors, including the vegetation types and water sources, were added into the model to produce potential habitat suitability maps of red-crowned crane without human disturbances (Fig. 1, a-c). Secondly, we further added the human disturbance factors, including the distance to road, oil well and residential area, into the model step by step. Therefore, we can examine the independent and joint effects of roads, oil wells, and residential area. When all the human disturbance factors were added into the model, the habitat suitability maps of red-crowned crane with human disturbances were generated (Fig. 1, d-f).

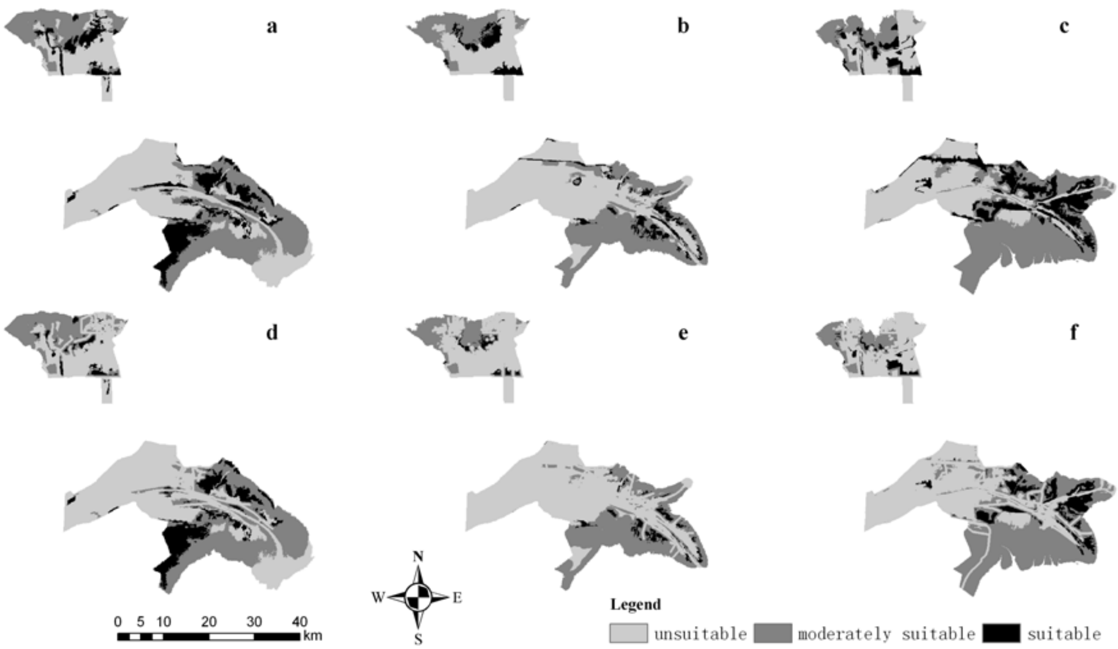

Fig. 1 Habitat suitability map of red-crowned crane without and with human disturbance activities from 1992 to 2006

a,b,c : maps without human disturbances of 1992,1999,2006,respectively; d,e,f: maps with human disturbances of 1992,1999,2006,respectively

Analysis methods

Based on the habitat suitability maps of red-crowned crane, fragstats software 3.3 was used to calculate the appropriate landscape indices that reflect habitat area change and degree of habitat fragmentation. In this paper, seven indices were selected as follows: total area (TA) that indicates habitat area change, numbers of patch (NP), patch density (PD) and mean patch area (AREA_MN) that show the degree of habitat fragmentation, perimeter-area fractal dimension (PAFRAC) that reveals the shape characteristic of habitat patches (O'Neil et al. 1988), proximity index (PROX_MN) that reflects the degree of isolation between habitat patches (Gustafson et al. 1992), and aggregation Index (AI) that explains the patch of class types' aggregation level (He et al. 2000). The details of the indices are described in the Table 2 (McGarigal et al. 2002).

Table 2. Description of metrics quantify landscape pattern and structure

Index	Description
TA	Total area of the same habitat type
NP	The number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares).
PD	The number of patches of the corresponding patch type (class).
AREA_MN	The sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10 000 (to convert to hectares); that is, total class area.
PAFRAC	2 divided by the slope of regression line obtained by regressing logarithm of patch area (m^2) against the logarithm of patch perimeter (m). PAFRAC approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.
PROX_MN	The sum of patch area (m^2) divided by the nearest edge-to-edge distance squared (m^2) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch. PROX = 0, if a patch has no neighbors of the same patch type within the specified search radius. PROX increases as the neighborhood is increasingly occupied by patches of the same type.
AI	The number of like adjacencies involving the corresponding class, divided by the maximum possible number of like adjacencies involving when the class is maximally clumped into a single, compact patch; multiplied by 100. AI equals 0 when the focal patch type is maximally disaggregated; AI increases as the focal patch type is increasingly aggregated and equals 100 when the patch type is maximally aggregated into a single and compact patch.

Results

Analysis of habitat area changes

The total areas of red-crowned crane‘s habitat in YRDNR were calculated with and without human disturbance activities in 1992, 1999 and 2006, respectively (Table 3, 4). Overall, since 1992, the proportions of suitable habitat area and moderately suitable habitat area without human disturbances was below 17.5% and higher than 36.3%, respectively, and the highest both occurred in 2006. Meanwhile, the suitable and moderately suitable habitat area without human disturbances were decreased from 1992 to 1999 and increased from 1999 to 2006 (Table 3).

Compared with oil well or residential area disturbances, the road disturbances had a larger contribution to the habitat loss (Table 4). On the other hand, the suitable habitat loss was increased from 1992 to 2006 rapidly due to human disturbances. As a result, the suitable habitat area in 2006 was less than that in 1992. Although moderately suitable habitat reflected the same trend as suitable habitat, the largest habitat area still occurred in 2006 (Table 4).

Inclusion, whether human disturbances exist or not, total area of suitable and moderately suitable habitat in 1999 is the lowest among the three years. Furthermore, due to human disturbances, the area of habitat loss, including suitable and moderately suitable habitat, increased from 1992 to 2006, especially from 1999 to 2006.

Table 3. Total habitat area in different grades of affecting factors without human disturbance activities

Year	Suitable habitat		Moderately suitable habitat		Unsuitable habitat	
	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)	Area (ha)	Proportion (%)
1992	19106	16.3	42942	36.7	55056	47.0
1999	8946	8.7	37743	36.3	56845	55.0
2006	19454	17.5	48467	43.5	43509	39.0

Table 4. Habitat area of different grades of affecting factors with human disturbance activities

Type	Year	Excluding roads		Excluding oil wells		Excluding residential areas		Excluding joint human disturbances	
		Area (ha)	Decreased (ha)	Area (ha)	Decreased (ha)	Area (ha)	Decreased (ha)	Area (ha)	Decreased (ha)
Suitable	1992	14648	4458	17641	1465	19013	3	14243	4863
	1999	4494	4452	7000	1946	8568	378	3918	5028
	2006	10153	9301	16326	3128	18536	918	9676	9778
Moderately suitable	1992	42541	401	42715	227	42902	40	41968	974
	1999	35593	2150	35478	2265	37652	91	34174	3569
	2006	47363	1104	46773	1694	48459	8	45545	2922

Analysis of habitat fragmentation

We calculated six landscape indices (NP, PD, AREA_MN, PAFRAC, PROX_MN, and AI) to reveal the reason of habitat fragmentation of red-crowned crane (Table 5, Fig. 3). As to suitable habitat, AREA_MN, PROX_MN and AI decreased from 1992 to 1999, and increased from 1999 to 2006, while PAFRAC showed the opposite trend with or without human disturbances. It indicated that during the period of 1992–1999, contrasting to 1999–2006, the fragmentation degree of suitable habitat became more severe, moreover, the isolation degree and shapes of suitable habitat became more dispersed and complex, respectively whether ever the human disturbances existed or not,

Moderately suitable habitat showed different trend as suitable habitat from 1992 to 2006 with and without human disturbances (Table 5, Fig. 3). The lowest degree of fragmentation in moderately suitable habitat happened in 1999 without human disturbances, and in 1992 with human disturbances. In addition, PROX_MN showed that the isolation degree of moderately suitable habitat in 1999 was the highest whether human disturbances existed or not, but the PAFRAC showed that the shapes of moderately suitable habitat changed little since 1992.

The results also indicated that human disturbances worsened the fragmentation and isolation degree of suitable and moderately suitable habitat (Table 5), especially in 2006. In addition, the road disturbances also had the biggest contribution to the fragmentation and isolation of suitable and moderately suitable habitat of red crown crane (Table 6).

Discussion

Habitat loss and fragmentation are the main factor for the endangered and extinction of species and the declines of global biodiversity (Burkey 1995; Wilcove et al. 1998). Red-crowned crane is a big wetland bird with large scale's habitat requirement and highly specialized habitat preferences. Wetland loss and fragmentation have great impacts on reproduction and survival of red-crowned crane (Hu et al. 2004; Zhang et al. 2006). Su et al (2004) concluded that the suitable habitat of red-crowned crane decreased from 1986 to 2001 in Yellow River Delta due to increasing wetland fragmentation caused by the intensive human disturbance activities. However, our results indicated that habitat suitability of red-crowned crane declined from 1992 to 1999, but enhanced from 1999 to 2006 because of different spa-

tial-temporal scales and study methods used.

Table 5. Landscape indices of red-crowned crane's habitat

Disturbances	Types	Year	NP	PD	AREA_MN	PAFRAC	PROX_MN	AI
Without disturbance	Suitable habitat	1992	97	0.0828	196.97	1.3071	1073.15	95.86
		1999	111	0.1072	80.59	1.4034	439.91	91.66
		2006	130	0.1167	149.65	1.2989	1360.66	95.93
	Moderately suitable habitat	1992	94	0.0803	456.83	1.3086	9208.96	97.65
		1999	70	0.0676	539.18	1.3200	4544.28	97.27
		2006	113	0.1014	428.91	1.3124	11402.99	97.82
Joint disturbances	Suitable habitat	1992	137	0.117	103.96	1.2628	746.93	95.89
		1999	140	0.1352	27.98	1.4021	140.78	88.72
		2006	155	0.1391	62.43	1.2736	271.13	95.13
	Moderately suitable habitat	1992	181	0.1546	231.87	1.2928	3280.49	97.34
		1999	175	0.169	195.28	1.2959	1360.22	96.99
		2006	230	0.2064	198.02	1.2724	3256.15	97.32

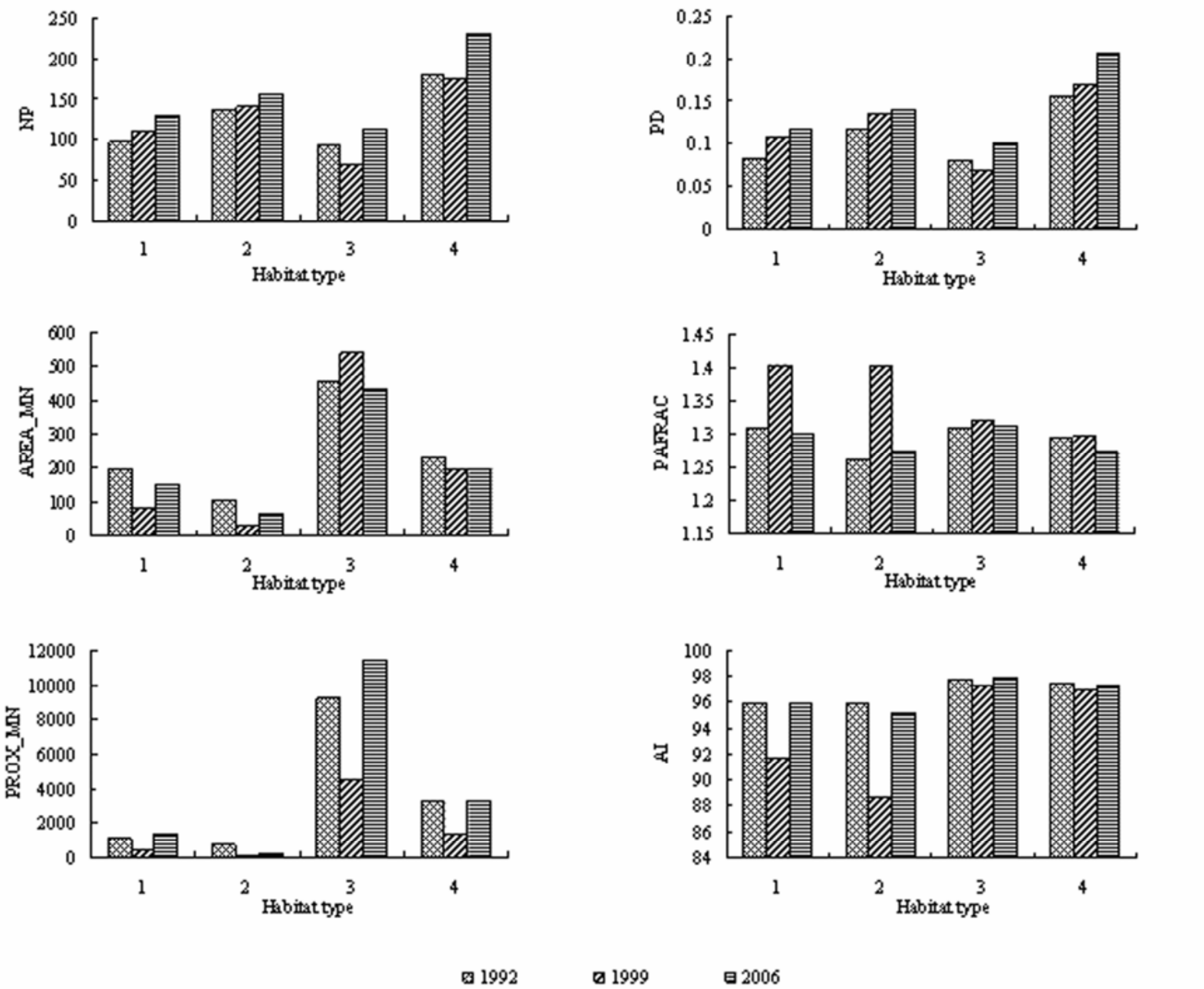

Fig. 3 Landscape indices of suitable and moderately habitat

1. Suitable habitat without human disturbances; 2. Suitable habitat with human disturbances; 3. Moderately suitable habitat without human disturbances; 4. Moderately suitable habitat with human disturbances.

Table 6. Landscape indices of red-crowned crane's habitat with different human disturbance activities

Year	Types	Suitable habitat				Moderately suitable habitat			
		NP	AREA_MN	PROX_MN	PAFRAC	NP	AREA_MN	PROX_MN	PAFRAC
1992	Residential area	99	192.05	1059.06	1.3073	93	462.18	9150.16	1.3103
	Oil wells	115	153.40	801.65	1.3028	125	341.72	7827.03	1.3181
	Roads	138	106.15	759.12	1.263	170	250.24	3413.79	1.2862
1999	Residential area	112	76.50	441.23	1.4042	73	515.77	4079.63	1.3237
	Oil wells	133	52.63	204.92	1.4025	119	298.13	3521.97	1.319
	Roads	141	31.88	187.84	1.3908	164	217.03	1472.59	1.2903
2006	Residential area	132	140.42	1183.67	1.3029	124	390.80	10367.91	1.311
	Oil wells	158	103.33	715.19	1.2954	166	281.77	7923.28	1.3165
	Roads	151	67.24	289.67	1.2781	220	215.29	3475.44	1.258

Two main factors resulting in habitat loss and fragmentation of red-crowned crane are natural and human activity factor. Fresh water sources, which are determined mainly by the Yellow River runoff, are the main natural factor. The zero flow of Yellow River occurred frequently since 1972. Especially in 1990's, the frequency of zero flow increased significantly and the continuous period enlarged smartly in Yellow River (Yang 2005). From 1995 to 1998, the continuous periods were over 100 days, and the longest period, which occurred at Lijin hydrological station in 1997, was 227 days (Table 7). Consequently, large amounts of wetlands in YRDNR were degraded. More habitat areas of red-crowned crane reduced subsequently. However, since 2002, the Yellow River Conservancy Commission (YRCC) has begun to perform water and sediment regulation to increase the water supplements for the downstream of Yellow River. At the same time, Managers of YRDNR initiated the wetland restoration project to restore the degraded wetlands. All those measures enhanced the wetland quality and the habitat suitability of red-crowned crane. It was shown that the water resource area increased from 7 836 ha to 19 888 ha, and the number of tide ditches increased from 121 to 144 during 1999 to 2006 (Table 8).

Table 7. Period of zero flow in Yellow River at Lijin hydrological station in 1990's

Zero flow	Year								
	1991	1992	1992	1994	1995	1996	1997	1998	1999
Days	16	82	61	75	122	132	226	142	42

Table 8. Description statistics of water sources and disturbance factors

Year	Water source factors		Disturbance factors		
	Water area (ha)	Number of tide ditches	Length of roads (km)	Number of oil wells	Residential area (ha)
1992	12535	137	297	151	416
1999	7836	121	483	482	611
2006	19888	144	547	511	613

Road and oil wells are the main human activities. With the development of oil industry, many roads, oil wells, and industry buildings were built up in YRDNR. Since 1992, 250-km new roads and 360 new oil wells were increased in YRDNR (Table 8). As a result, human disturbance activities worsened the habitat loss and fragmentation of red-crowned crane.

Conclusions

Overall, due to scarcities of fresh water sources in YRDNR caused by zero flow of Yellow River from 1992 to 1999, habitat suitability of red-crowned crane in 1999, with more habitat loss and fragmentation, was inferior to that in 1992 and 2006 no matter whether human disturbances existed or not. However, since YRCC performed water and sediment regulation and YRDNR initiated the wetland restoration projects in 2002, habitat suitability of red-crowned crane would be improved significantly in 2006 if there were not human disturbance activities. On the other hand, human disturbances were another main factor that resulted in declining habitat suitability of red-crowned crane. And road disturbances have the biggest contribution to habitat loss and fragmentation of red-crowned crane. Consequently, compared to no human disturbances, habitat suitability of red-crowned crane in 2006 was inferior to that in 1992 because human disturbances increased rapidly from 1992 to 2006.

References

Andren H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat- a review. *Oikos*, **71(3)**: 355–366.

Burkey TV. 1995. Extinction rates in archipelagoes: implications for population in fragmented habitats. *Conservation Biology*, **9**(3): 527–541.

Chen Liding, Liu Xuehua and Fu Bojie. 1999. Evaluation on Giant Panda habitat fragmentation in Wolong nature reserve. *Acta Ecological Sinica*, **19**(3): 291–297. (In Chinese)

Cushman SA. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. *Biological Conservation*, **128**(2): 231–240.

Dooley JL, Bowers MA. 1998. Demographic responses to habitat Fragmentation: experimental tests at the landscape and patch scale. *Ecology*, **79**(3): 968–980.

Fahrig L. 1997. Relative effects of habitat loss and fragmentation on popula-

tion extinction. *Journal of Wildlife Management*, **61**(3): 603−610.

Fahrig L. 2003. Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology Evolution and Systematics*, **34**: 487−515.

Flather CH, Bevers M. 2002. Patchy reaction-diffusion and population abundance: the relative importance of habitat amount and arrangement. *The American Naturalist*, **159**(1): 40−56.

Gibbs JP. 2000. Wetland loss and Biodiversity conservation. *Conservation Biology*, **14**(1): 314-317.

Gustafson EJ, Parker GR. 1992. Relationships between landcover proportion and indices of landscape spatial pattern. *Landscape Ecology*, **7**(2): 101−110

He HS, DeZonia BE, Mladenoff DJ. 2000. An aggregation index (AI) to quantify spatial patterns of landscapes. *Landscape Ecology*, **15**(7): 591−601.

IUCN. 2007. 2007 *IUCN Red List of threatened species*. Available at the following website: http://www.iucn.org/themes/ssc/redlist.htm

Laurance WF, Lovejoy TE, Vasconcelos HL, et al. 2002. Ecosystem decay of Amazonian forest fragments: a 22 year investigation. *Conservation Biology*, **16**(3): 605−618.

Li Fangman, Li Peixun. 1998. A comparative study on territories of white-naped crane and red-crowned crane. *Acta Zoologica Sinica*, **44**(1): 109−111. (In Chinese)

Li Feng, Yang Hongjun, Zhang Honghai. 1999. The nest-site selection by red-crowned crane in the Zalong wetland. *Journal of Northeast Forestry University*, **27**(6): 57−60. (In Chinese)

Li Wenjun, Wang Zijian. 2000. A winter habitat model for red-crowned crane. *Chinese Journal of Applied Ecology*, **11**(6): 839−842. (In Chinese)

Li Wenjun, Ma Zhijun, Wang Zijian, Tang Hongxiao, Wang Hui, Liu Xiping. 1999. A study on influential aspects relevant with habitat in natural reserve. *Acta Ecologica Sinica*, **19**(3): 427−430. (In Chinese)

Li Wenjun, Wang Zijian, Ma Zhijun, Tang Hongxiao, Wang Hui, Liu Xiping. 1997. The study of distribution of red-crowned crane's winter habitat in Yancheng nature reserve. *Man and biosphere*, **4**(3): 3−7. (In Chinese)

Li Xiaomin. 2002. The present status and conservation of red-crowned crane in Halahai wetland, Heilongjiang, China. *Chinese Journal of Zoology*, **37**(1): 64−66. (In Chinese)

Liu Bai. 1990. Winter numbers distribution of red-crowned crane on seaboard of yangcheng of Jiusu Province. *Acta Ecologica Sinica*, **10**(3): 284−285. (In Chinese)

Liu Zhensheng, Wu Jianping, Li Xiaomin, Teng Liwei, Wang Xiaoming, Guo Wenli, Qi Zhi, Yao Hongwei. 2001. Behavior of red-crowned crane during breeding season in zhalong nature reserve. *Journal of Northeast Forestry University*, **29**(6): 92−95. (In Chinese)

Ma Zhijun, Liu Xiping. 1998. Habitat change and suitability of red-crowned crane in Yancheng biosphere nature reserve. *Man and Biosphere*, **5**(2): 5−8. (In Chinese)

McGarigal K, Cushman SA, Neel MC. et al. 2002. FRAGSTATS Documentation, Available at the following website: http: //www.umass.edu/landeco/research/fragstats/documents/fragstats_documents.html.

Odum EP. 1971. Fundamental of Ecology. Philadelphia P H.A.B: Saunder Company.

O'Neill RV, Krummel JR, Gardne, RH. 1988. Indices of landscape pattern. *Landscape Ecology*, **1**: 153−162.

Ouyang Zhiyun, Wang Rusong. 1996. Ecological niche suitability model and its application in land suitability assessment. *Acta Ecologica Sinica*, **16**(2): 113−120. (In Chinese)

Schmiegelow FKA, Monkkonen M. 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. *Ecological Application*, **12**(2): 375−389.

Stephens SE, Koons DN, Rotella JJ, Willey DW. 2003. Effects of habitat fragmentation on avian nesting success: a review of the evidence at multiple spatial scales. *Biological Conservation*, **115**(1): 101−110.

Su Ying, Hu Yuanman, Guo Dufa, Shan Kai, Zhu Shuyu, Wang Lidong. 2004. The change of habitat suitable for the red-crowned crane in Yellow River Delta. *Chinese Journal of Zoology*, **39**(3): 33−41. (In Chinese)

Su Ying, Hu Yuanman, Leng Wenfang, Zhu Shuyu, Shan Kai. 2006. The habitat selection of red-crowned crane at autumn and winter in Yellow River Delta. *Chinese Journal of Ecology*, **25**(8): 954−958. (In Chinese)

Wan Dongmei, Gao Wei, Wang Qiuyu, Wang Haitao, Liu Mingyu. 2002. Effects of habitat fragmentation on nesting site selection of red-crowned crane. *Chinese journal of applied ecology*, **13**(5): 581−584. (In Chinese)

Wilcove DS, Rothstein D, Dubow J, Philips A, Losos E. 1998. Quantifying threats to imperiled species in the Unite States. *BioScience*, **48(8)**: 607−615.

Wu Jianping, Liu Zhensheng, Li Xiaomin, teng Liwei, qiu Fuchen, wang Xiaoming, Qi Zhi, Yao Hong Wei, Guo Wenli. 2002. Breeding Behavior of red-crowned crane in zalong reserve. *Chinese Journal of Zoology*, **37**(5): 42−46. (In Chinese)

Xiao Duding, Hu Yuanman, Li Xiuzhen. 2001. *Landscape ecology research at wetland surrounding Bohai sea delta*. Beijing: Science Press, 106−107. (In Chinese)

Yang Likai. 2005. Effect of agricultural eco-environment from Huanghe River cessation in huanghe River delta area and its countermeasure. *China Environment Management*, **3**: 27−30. (In Chinese)

Zhang Peiyu, Li Guizhi. 2001. Study of red-crowned crane about its winter quarters and measures of protecting. *Journal of Biology*, **18**(2): 9−10. (In Chinese)

Zhang Yanhong, Deng Wei, Zhang Shuwei. 2006. The spatial structure analysis of the red-crown crane's habitat in xianghai national nature reserve based on RS and GIS techniques. *Acta Ecologica Sinica*, **26**(11): 3725−3731. (In Chinese)

Zhao Yangmao. 1995. *Scientific survey of the Yellow River Delta Nature Reserve*. Beijing: China Forestry Press, 115−117. (In Chinese)